

## HEWLETT-PACKARD COMPANY

## PATENT APPLICATION

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IN THE U.S. PATENT AND TRADEMARK OFFICE  
Patent Application Transmittal Letter

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Sir:

Transmitted herewith for filing under 37 CFR 1.53(b) is a(n): ☒ Utility ☐ Design  
☒ original patent application,  
☐ continuation-in-part application

INVENTOR(S): Robert Paasch

TITLE: Print Head Apparatus With Malfunction Detector

Enclosed are:

☒ The Declaration and Power of Attorney. ☒ signed ☐ unsigned or partially signed  
☒ 2 sheets of drawings (one set) ☐ Associate Power of Attorney  
☐ Form PTO-1449 ☒ Information Disclosure Statement and Form PTO-1449  
☐ Priority document(s) ☐ (Other) (fee \$ )

CLAIMS AS FILED BY OTHER THAN A SMALL ENTITY				
(1) FOR	(2) NUMBER FILED	(3) NUMBER EXTRA	(4) RATE	(5) TOTALS
TOTAL CLAIMS	27 — 20	7	X \$18	\$ 126
INDEPENDENT CLAIMS	6 — 3	3	X \$78	\$ 234
ANY MULTIPLE DEPENDENT CLAIMS	0		\$260	\$ 0
BASIC FEE: Design \$310.00 ); Utility \$760.00 )				\$ 760
TOTAL FILING FEE				\$ 1,120
OTHER FEES				\$
TOTAL CHARGES TO DEPOSIT ACCOUNT				\$ 1,120

Charge \$ 1,120 to Deposit Account 08-2025. At any time during the pendency of this application, please charge any fees required or credit any over payment to Deposit Account 08-2025 pursuant to 37 CFR 1.25. Additionally please charge any fees to Deposit Account 08-2025 under 37 CFR 1.16, 1.17, 1.19, 1.20 and 1.21. A duplicate copy of this sheet is enclosed.

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I hereby certify that this is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated above and is addressed to: Assistant Commissioner for Patents, Washington, D.C. 20231.

By

Typed Name: Raymond A. Jensi

Respectfully submitted,

Robert Paasch

By

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PRINT HEAD APPARATUS WITH MALFUNCTION DETECTOR

Inventor(s): Robert Paasch

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FIELD OF THE INVENTION

The present invention relates to print heads used in  
printers and plotters and the like and, more specifically,  
10 to detecting malfunctions within such print heads.

BACKGROUND OF THE INVENTION

Printers and plotters are known in the art and  
include those made by Hewlett-Packard, Canon and Epson,  
15 amongst others. In the discussion that follows, printers  
and plotters are referred to collectively with the term  
"printers". Problems associated with current printers and  
print head arrangements include that the print head may  
run out of ink while printing, the print head nozzle may  
20 become clogged and the ink expulsion mechanism may not  
fire, amongst other malfunctions. Evidence of such  
malfunctions are usually detected when the printed  
document is pulled out of the printer and examined  
visually. At this point it is too late for appropriate  
25 correction. Some types of electronic sensing are known in  
the art, such as techniques for detecting when an ink  
expulsion mechanism has not fired. These techniques,  
however, are limited in scope and do not, for example,  
detect when a nozzle is clogged or unclogged.

30 A need thus exists to detect print head malfunction  
in such a manner as to eliminate or minimize corruption of

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a printed image. Early detection of a malfunction permits preventative steps to be taken such as print head replacement or software based compensation within the firing algorithm, etc.

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SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a print head that can detect a malfunction therein.

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It is another object of the present invention to provide a print head that can detect such conditions as a clogged nozzle, no fire and dry fire.

15

It is another object of the present invention to provide a print head that incorporates a pressure sensor and circuitry therefor that detects firing of an ink expulsion mechanism and determines characteristics about the firing based on the sensed signals.

20

It is also an object of the present invention to provide a print head with a piezoelectric type pressure sensor.

These and related objects of the present invention are achieved by use of a print head apparatus with a malfunction detector as described herein.

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The attainment of the foregoing and related advantages and features of the invention should be more readily apparent to those skilled in the art, after review of the following more detailed description of the invention taken together with the drawings.

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BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a cross sectional side view of a print head in accordance with the present invention.

Fig. 2 is a side view of a piezoelectric acoustic  
5 wave transducer in accordance with the present invention.

Fig. 3 is a side view of a portion of an interdigitated pressure wave transducer in accordance with the present invention.

Fig. 4 is a plan view of an arrangement of  
10 piezoelectric acoustic pressure wave transducers and interdigitated piezoelectric pressure wave transducers in a print head in accordance with the present invention.

Fig. 5 is a graph of illustrating the pressure on an expulsion mechanism surface versus time for a clogged  
15 nozzle firing and an unclogged nozzle firing is shown.

DETAILED DESCRIPTION

Referring to Fig. 1, a cross sectional side view of a print head 10 in accordance with the present invention is  
20 shown. Print head 10 includes a substrate in or on which is provided an ink expulsion mechanism 14. Ink expulsion mechanism 14 may expel ink through thermal or mechanical excitation or through other appropriate expulsion means. In a preferred embodiment, mechanism 14 is thermally  
25 actuated and may be implemented with a resistive element as is known in the art. Ink expulsion mechanism 14 is controlled by off-die circuitry or by a combination of on-die and off-die circuitry as is known. Representative off-die coupling is indicated by signal line 15 and contact  
30 pad 16.

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A barrier layer 20 is formed on substrate 12 and an orifice plate 30 is formed on barrier layer 20. The substrate, barrier layer and orifice plate define an ink well or conduit 24 that channels ink from a supply (not shown) into proximity with the expulsion mechanism. An orifice or nozzle 31 through which ink is expelled is formed in the orifice plate and positioned over ink expulsion mechanism 14. Suitable material for barrier layer 20 and orifice plate 30 are known in the art.

Assuming that ink expulsion mechanism 14 is a thermally actuated device such as a resistor, an ink drop is expelled by essentially boiling a drop of ink through nozzle 31. During formation and collapse of a boiling ink bubble, a series of acoustic pressure waves 26 (hereinafter referred to as "pressure waves") are produced. These waves propagate through the components of the print head, including primarily the substrate and ink well. In the substrate (and conventional thin film layers formed thereon), both longitudinal and shear waves are produced. Longitudinal waves can be detected by an interdigitated piezoelectric pressure wave transducer 50 or the like which is described in more detail with reference to Figs. 3 and 4. In ink well 24, longitudinal pressure waves are produced. These waves can be detected with a piezoelectric acoustic pressure wave transducer 40 which is described in more detail with reference to Fig. 2. For purposes of the present discussion, the term "interdigitated transducer" will be used for the interdigitated piezoelectric pressure wave transducer and the term "acoustic transducer" will be used for the piezoelectric acoustic pressure wave transducer. While

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both an acoustic transducer and an interdigitated transducer are described as being provided on substrate 12, it should be recognized that they need not be provided together because either transducer is capable of sufficiently detecting pressure waves. The provision of both provides redundancy.

Acoustic transducer 40 and interdigitated transducer 50 are preferably coupled to processing circuit 60. Processing circuit 60 preferably includes an amplifier, a filter and an analog to digital converter or related signal processing circuitry. Processing circuit 60 may be configured to provide the necessary processing to determine dry-fire, no-fire and clogged-fire conditions (that is, a misfire) or the sensor output signals can be delivered to off-die logic 70 for such processing. The output of processing circuit 60 is propagated over signal line 17 to contact pad 18.

Referring to Fig. 2, a side view of an acoustic transducer in accordance with the present invention is shown. Fig. 2 illustrates the acoustic transducer of Fig. 1 in more detail. Fig. 2 illustrates substrate 12 on which the following layers are formed: an insulation layer 21, a conductive coupling layer 41, piezoelectric material 42, a first and a second signal conductive layer 44,45, a passivation layer 47 and a surface coat layer 48. In a preferred embodiment, these layers are made of the following or a like material: insulation layer 21 is silicon dioxide ( $\text{SiO}_2$ ), conductive layer 41 is tantalum aluminum (TaAl), piezoelectric material 42 is aluminum nitride (AlN), first and second conductive layers or traces 44,45 are aluminum (Al), passivation layer 47

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includes a first layer of silicon nitride ( $\text{Si}_3\text{N}_4$ ) and a second layer of silicon carbide ( $\text{SiC}$ ), and coating 48 layer is tantalum ( $\text{Ta}$ ). It should be recognized that the arrangement and composition of these layers may be altered in a manner consistent with device fabrication techniques without deviating from the present invention. It should also be recognized that other piezoelectric material such as zinc oxide ( $\text{ZnO}$ ) or PZT may be used and that other types of suitable pressure sensors may be used.

The first and second conductive layers 44,45 form conductors for reading a voltage generated by piezoelectric material 42 in response to an incident pressure wave. A pressure wave traveling through the ink well compress the thin film stack, resulting in a mechanical strain in the thin film layers. In the piezoelectric layer, this strain produces a measurable electric charge across the two conductors.

Referring to Fig. 3, a side view of a portion of an interdigitated transducer in accordance with the present invention is shown. Fig. 3 illustrates the interdigitated transducer of Fig. 1. The layout of this transducer and its arrangement with another interdigitated transducer are shown in Fig. 4. Fig. 3 illustrates substrate 12 on which are formed insulation layer 21, piezoelectric material 52, first and second conductors 54,55 (only one of which is shown), a passivation layer 57 and a coating layer 58. The substrate, insulation layer, passivation layer and coating layer are as discussed above for acoustic transducer 40. The piezoelectric material and conductive layers are preferably similar in composition to their

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counterparts in transducer 40, however, their areal arrangement is different as shown in Fig. 4.

Referring to Fig. 4, a plan view of an arrangement of acoustic transducers and interdigitated transducers in a print head in accordance with the present invention is shown. Fig. 4 illustrates substrate 12, a plurality of ink expulsion mechanisms 14, barrier layer 20, ink well 24, a plurality of acoustic transducers 40 and a plurality of interdigitated transducers 50. Orifice plate 30 would be placed over the arrangement of Fig. 4 with nozzles aligned with the ink expulsion mechanisms 14. It should be recognized that the transducer arrangement disclosed in Fig. 4 is representative and provided for pedagogical purposes. The ink expulsion mechanisms ink well and the size number and arrangement of transducers may be modified from that of Fig. 4 without departing from the present invention. Furthermore, it should be recognized that although the interdigitated transducers are shown in the ink well, since they detect pressure waves in the substrate they may be placed anywhere on the substrate including under the barrier layer.

The interdigitated transducers are preferably implemented as interdigitated conductors 54-55 placed over a corresponding pattern of piezoelectric material 52. These interdigitated transducers exhibit a directional detection characteristic that is advantageous to some implementations of the present invention. Fig. 4 illustrates two interdigitated pressure wave transducers 50 and 50' that are arranged orthogonally to one another. This arrangement facilitates detection of pressure waves traveling in different directions. The acoustic



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transducers 40 of Fig. 4 are essentially as described above with references to Figs. 1 and 2. Each of transducers 40 and 50 are shown with their first and second conductors 44,45 and 54,55, respectively being  
5 coupled to vias 13 (under the barrier layer) that are coupled to signal processing circuit 60 of Fig. 1.

Referring to Fig. 5, a graph illustrating the pressure on the surface of resistor or expulsion mechanism 14 verses time for a clogged nozzle firing and an  
10 unclogged nozzle firing is shown. As alluded to above, the cavitation of the air bubble(s) at resistor or expulsion mechanism 14 during firing causes a considerable pressure spike on the surface of the resistor. This pressure spike is normally around 20MPa (greater than 10K PSI) and occurs  
15 at approximately 13.5 $\mu$ S after firing. When the nozzle associated with a particular resistor is clogged, however, the pressure spike has a different signature. Typically it is lower in magnitude by about 15-25 percent (e.g., approximately 16Mpa) and occurs earlier (e.g., 15-20%  
20 earlier, usually approximately 11 $\mu$ S). The combination of decreased magnitude and quicker response time permits differentiation of an unclogged firing from a clogged firing. The absence of a pressure wave indicates a "no-fire" event.

25 While the invention has been described in connection with specific embodiments thereof, it will be understood that it is capable of further modification, and this application is intended to cover any variations, uses, or adaptations of the invention following, in general, the  
30 principles of the invention and including such departures from the present disclosure as come within known or

customary practice in the art to which the invention pertains and as may be applied to the essential features hereinbefore set forth, and as fall within the scope of the invention and the limits of the appended claims.

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CLAIMS

1. A print head apparatus, comprising:  
a substrate;  
5 an ink expulsion mechanism provided on said substrate; and  
a first pressure sensor that is capable of detecting a signal related to a misfiring of said ink expulsion mechanism.
- 10 2. The apparatus of claim 1, wherein said sensor includes piezoelectric material.
- 15 3. The apparatus of claim 1, wherein said sensor is formed on said substrate.
4. The apparatus of claim 1, further comprising:  
a barrier layer formed on said substrate;  
a cover plate having a nozzle therein formed on said  
20 barrier layer and positioned such that said nozzle is aligned with said ink expulsion mechanism, said substrate, barrier and cover plate defining an ink well; and  
wherein said first sensor is provided at said ink well in such a manner as to detect pressure waves  
25 propagating in ink in said ink well caused by a misfiring of said ink expulsion mechanism.
5. The apparatus of claim 1, wherein said first pressure sensor is an acoustic wave piezoelectric  
30 transducer.

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6. The apparatus of claim 1, wherein said first pressure sensor is an interdigitated pressure wave transducer.

5 7. The apparatus of claim 1, further comprising a second pressure sensor, wherein said first pressure sensor is an acoustic wave piezoelectric transducer and said second pressure sensor is an interdigitated pressure wave transducer.

10 8. The apparatus of claim 1, wherein said ink expulsion mechanism is thermally actuated.

15 9. The apparatus of claim 6, further comprising a second pressure sensor that is an interdigitated pressure wave transducer and said first sensor and said second sensor are provided in a substantially orthogonal arrangement on said substrate.

20 10. A print head apparatus, comprising:  
a substrate;  
an ink expulsion mechanism formed on said substrate;  
a cover plate spaced from said ink expulsion  
mechanism and having a nozzle formed therein, said nozzle  
25 being aligned with said ink expulsion mechanism; and  
a sensor mechanism that is capable of determining  
when said nozzle is clogged.

30 11. The apparatus of claim 10, wherein said sensor mechanism is capable of determining when said nozzle is unclogged.

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12. The apparatus of claim 10, wherein said sensor  
mechanism is capable of determining one or more of the  
group of conditions including dry-fire and no-fire  
5 conditions.

13. The apparatus of claim 10, wherein said sensor  
is a pressure sensor.

10 14. The apparatus of claim 13, wherein said sensor  
includes piezoelectric material.

15 15. The apparatus of claim 10, wherein said sensor  
includes one or more of the group of sensors including an  
piezoelectric acoustic wave transducer and an  
interdigitated pressure wave transducer.

16. The apparatus of claim 10, wherein said sensor  
mechanism is capable of detecting a magnitude and timing  
20 of a pressure wave generated by a firing of said ink  
expulsion mechanism.

17. A method of monitoring performance of a print  
head, comprising the steps of:  
25 attempting expulsion of a volume of ink from a print  
head;

detecting within said print head a characteristic of  
a pressure wave generated by said attempt to expel said  
volume of ink.

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18. The method of claim 17, further comprising the step of determining from said detected characteristic a status of said attempted expulsion of said volume of ink.

5 19. The method of claim 17, wherein said detecting step includes the step of detecting the presence or absence of a pressure wave.

10 20. The method of claim 17, wherein said detecting step includes the step of detecting a magnitude and timing of said pressure wave.

15 21. The method of claim 20, wherein said detecting step further comprises the steps of establishing a first magnitude related to an expulsion of said volume of ink and detecting a second magnitude in the range of 15% to 25% less than said first magnitude.

20 22. The method of claim 20, wherein said detecting step further comprises the steps of establishing a first timing of said pressure wave related to an expulsion of said volume of ink and detecting a second timing in the range of 15% to 20% earlier than said first timing.

25 23. A printhead for an inkjet printing apparatus comprising:  
a substrate;  
at least one ink ejector disposed on said substrate;  
an interdigitated pressure wave transducer disposed  
30 on said substrate and having a directional detection characteristic whereby a pressure wave traveling in a

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predetermined direction from said at least one ink ejector is preferentially detected.

24. A printhead in accordance with claim 23 further  
5 comprising a second interdigitated pressure wave  
transducer disposed on said substrate and having a  
directional detection characteristic oriented such that a  
pressure wave traveling in a second direction different  
than said predetermined direction is preferentially  
10 detected.

25. A printhead in accordance with claim 24 wherein  
said second direction is orthogonal to said predetermined  
direction.

15 26. A method of detecting a misfiring nozzle in an  
inkjet printhead comprising the steps of:  
establishing a first magnitude of a pressure wave  
corresponding to an ejection of a predetermined volume of  
20 ink from a nozzle; and

detecting a second magnitude of a pressure wave in  
the range of 15% to 25% less than said first magnitude  
whereby a misfiring nozzle may be detected.

25 27. A method of detecting a misfiring nozzle in an  
inkjet printhead comprising the steps of:

establishing a first timing of an arrival of a  
pressure wave from an ejection of a predetermined volume  
of ink from a nozzle; and

detecting a second timing of an arrival of a pressure wave in the range of 15% to 20% earlier than said first timing whereby a misfiring nozzle may be detected.



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ABSTRACT OF THE DISCLOSURE

5 A print head and method that are capable of detecting  
a plurality of performance conditions such as a dry-fire,  
no-fire or clogged-nozzle condition. Pressure wave  
sensors within a print head are disclosed that are capable  
of detecting pressure waves generated by the firing of an  
ink expulsion mechanism. The characteristics of the  
10 pressure wave generated by the firing event (e.g.,  
magnitude and timing) are indicative of the operating  
condition within the head. Multiple sensor types are  
disclosed.

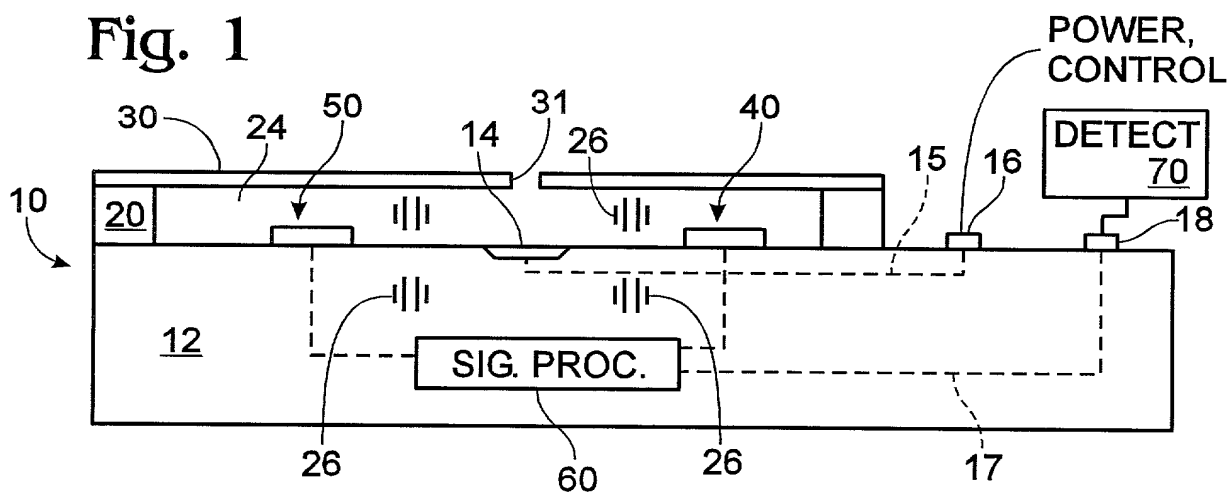


Fig. 4

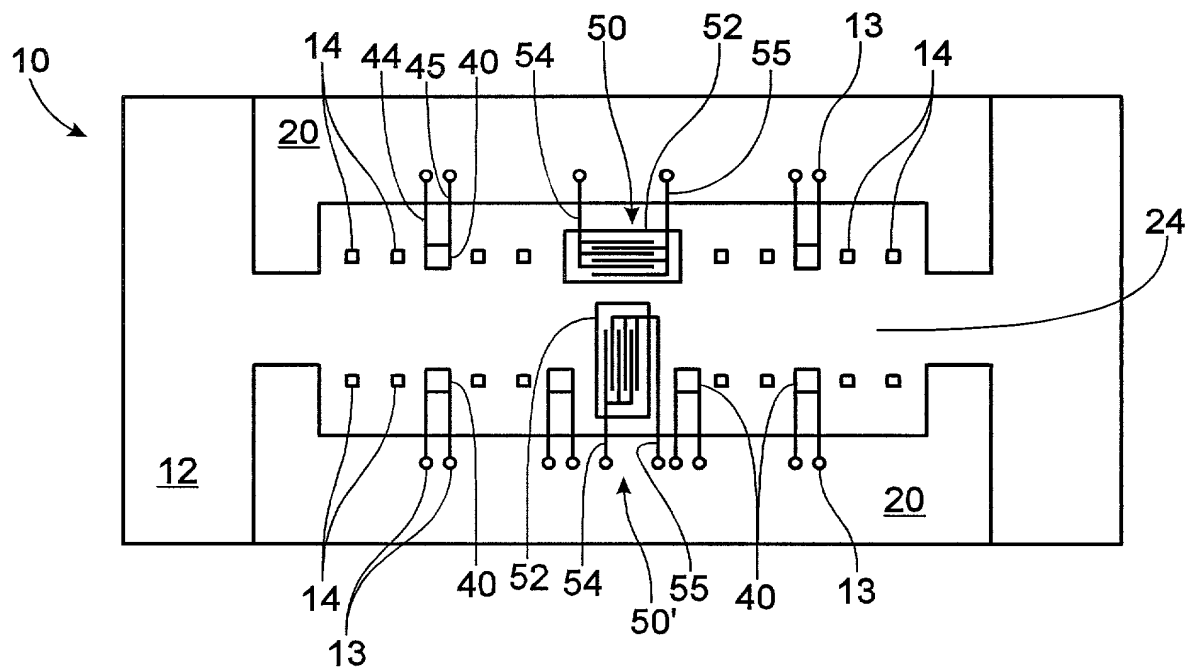
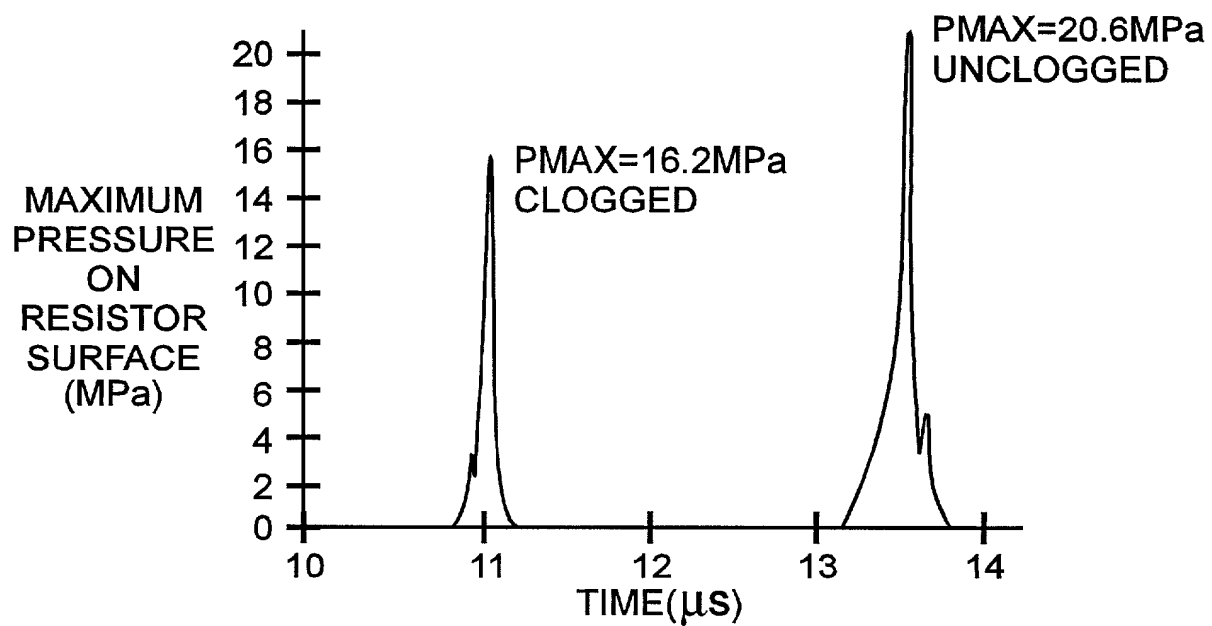


Fig. 5



**DECLARATION AND POWER OF ATTORNEY  
FOR PATENT APPLICATION**ATTORNEY DOCKET NO. 10980780-1

As a below named inventor, I hereby declare that:

My residence/post office address and citizenship are as stated below next to my name;

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

**Print Head Apparatus with Malfunction Detector**

the specification of which is attached hereto unless the following box is checked:

( ) was filed on \_\_\_\_\_ as US Application Serial No. or PCT International Application  
Number \_\_\_\_\_ and was amended on \_\_\_\_\_ (if applicable).

I hereby state that I have reviewed and understood the contents of the above-identified specification, including the claims, as amended by any amendment(s) referred to above. I acknowledge the duty to disclose all information which is material to patentability as defined in 37 CFR 1.56.

**Foreign Application(s) and/or Claim of Foreign Priority**

I hereby claim foreign priority benefits under Title 35, United States Code Section 119 of any foreign application(s) for patent or inventor(s) certificate listed below and have also identified below any foreign application for patent or inventor(s) certificate having a filing date before that of the application on which priority is claimed:

COUNTRY	APPLICATION NUMBER	DATE FILED	PRIORITY CLAIMED UNDER 35 U.S.C. 119
			YES: _____ NO: _____
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**Provisional Application**

I hereby claim the benefit under Title 35, United States Code Section 119(e) of any United States provisional application(s) listed below:

APPLICATION SERIAL NUMBER	FILING DATE

**U. S. Priority Claim**

I hereby claim the benefit under Title 35, United States Code, Section 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code Section 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, Section 1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

APPLICATION SERIAL NUMBER	FILING DATE	STATUS (patented/pending/abandoned)

**POWER OF ATTORNEY:**

As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) listed below to prosecute this application and transact all business in the Patent and Trademark Office connected therewith.

**Raymond A. Jensi****Kevin B. Sullivan****Michael D. Jones****Curtis G. Rose**

Reg. No. 31,267

Reg. No. 39,043

Reg. No. 37,157

Reg. No. 32,057

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full Name of Inventor: **Robert Paasch**Citizenship: **US**Residence: **110 NE Thousand Oaks Drive, Corvallis, OR 97330**Post Office Address: **Same as Residence**

Inventor's Signature

Date

10/12/99